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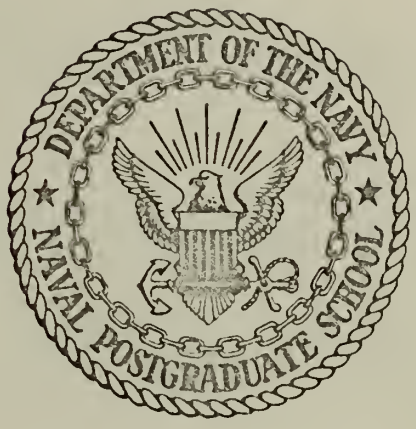

THESIS

A Symbolic
Sensitivity Computation Algorithm

by

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ABSTRACT

A study and pursuant development is described of a digital computer program for the computation of transfer function sensitivities in a symbolic form suitable for storage and subsequent repetitive numerical evaluation over a range of frequencies or parameter values. The algorithm is implemented in conjunction with the Network Analysis for Systems Applications Program (NASAP) version developed by R. S. Schwartz at Northeastern University. Several example problems, as well as suggestions for possible improvement of the algorithm and its extrapolation into the areas of optimization and automatic design, are included.

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I. INTRODUCTION

A. STATEMENT OF THE PROBLEM

The purpose of this research was twofold: (1) to investigate the feasibility of providing for the automatic digital machine computation of transfer function sensitivities in a symbolic form suitable for storage and subsequent numerical evaluation over a range of frequencies and parameter values or for use by a minimization/optimization procedure as a readily available source of gradient data, and (2) to implement such a program, if feasible, in conjunction with the Network Analysis for Systems Applications Program (NASAP).

There were formidable obstacles encountered in the course of the research which may best be illustrated by a preliminary examination of the computer core storage required for implementation of the proposed procedure if it were meshed with an existent circuit analysis program such as NASAP. The NASAP program is capable of manipulating up to 10,000 independent loop products (generated through use of topological flowgraph techniques), once as a numerator polynomial in s and once as a denominator polynomial; that is, by iterative use of a single vector variable, LOOP, dimensioned to 10,000. Each loop product may represent from one to twenty-three constituent elements, and the analytical expression for the partial derivative of a quotient involves four separate components - numerator polynomial, denominator polynomial, partial derivative of the numerator and partial derivative of the denominator. The implication, then, is a storage allocation requirement of four vector variables each of

dimension 230,000 words (920K bytes). This, of course, would provide for the sensitivity with respect to a single parameter; if the gradient is desired the requirement for the two partial derivative variables would be multiplied by a factor of 23 again, for a total of 11,500,000 words. Consider now an even more staggering statistic. Since the NASAP program, like most programs written in the FORTRAN language, assigns only one alphanumeric character to a word (four bytes in the IBM 360/67), there would be an additional factor of four; three for the element identifying characters and one for a code to indicate the algebraic formulation required. This initial examination, then, would indicate the need for an impossibly high storage allocation of 46,000,000 words (184,000K bytes!). Some degree of success was achieved in the reduction of this figure to a manageable size, but at the expense of limitations on the original objective. The extent of the progress and associated restrictions will become clear in later sections.

B. DISCUSSION OF THE NASAP PROGRAM

Prior to discussing the sensitivity algorithm in any detail, it would perhaps benefit the reader to summarize the characteristics and capabilities of NASAP since it is upon this foundation that the proposed technique is firmly based.

The revised version of NASAP is a digital computer program for the flowgraph analysis of lumped, linear active electrical networks designed to provide any desired circuit transfer function in either symbolic or numerical form. The program utilizes the "mixed" method to generate circuit equations, i. e., operations are performed on a tree-branch, link-branch topology so that Kirchoff's voltage law may be utilized to

express each link voltage in terms of tree voltages and Kirchoff's current law may be used to express each tree current in terms of link currents. These relationships, in association with volt-ampere and source dependency relationships, comprise a formulation defining a canonical form called a primitive flowgraph [3].

The user of NASAP prepares a circuit for analysis by: (1) converting to a linear model if necessary, (2) labeling each circuit element by type (R,L,C,V,I) and a two digit number which uniquely identifies it, and (3) numbering each node as desired except for the ground node which must be designated node 1. The user then inputs this connectivity data in the following format:

ELEMENT NAME	FROM NODE	TO NODE	ELEMENT VALUE	CONTROLLING PARAMETER (For controlled source)

Following this are coded sets of data describing the transfer functions desired, in the form of the ratio of a response variable (voltage or current associated with some circuit element) to an excitation variable (voltage or current), and the forms of program output desired. The NASAP tree-link hierarchy [20] and the order in which the elements were input to the program determines which elements are placed in the tree, thus providing the user with some flexibility regarding its choice. Given the topology, the machine then forms the fundamental outset matrix and from this constructs the primitive flowgraph.

A transfer function between any two nodes of the primitive flowgraph may be obtained by adding a "closure" [20] and solving the resulting "closed" graph by application of Mason's gain formula in the following manner. If the transfer function between node j and node k of a flowgraph is equal to T_{jk} and if the graph is then closed by the addition of

a branch from k to j whose transmission gain is equal to the reciprocal of T_{jk}, then the loop gain with the added branch is equal to unity and the determinant of the flowgraph vanishes. This reduces the solution of T_{jk} to the problem of summing loop-set transmittance products, a procedure highly suitable to machine solution. Readers desiring more detailed information concerning this procedure are directed to Ref. 20.

The procedures utilized by NASAP for labeling, sorting and storing each loop-set consist primarily of:

(1) As each loop-set is determined by the search routine, a signed integer label is generated from which the loop-set may be uniquely regenerated.

(2) Loop-sets with the same label but opposite sign are eliminated to reduce storage requirements.

(3) Loop-sets are sotted and stored in order of decreasing magnitude.

(4) The completed loop-set array represents the symbolic solution of either the numerator or denominator polynomial in coded form. From successive solutions the transfer function may be evaluated either numerically or symbolically by decoding and summing each loop.

C. A COMPARISON OF TWO FAVORABLE TOPOLOGICAL METHODS

A topological method other than the flowgraph procedure just described is the so-called "k-tree" approach [6] which is based on Maxwell's topological formulas for node voltage equations. That is, transfer functions are derived from the evaluation of determinants formed from circuit nodal equations; however, they may equivalently be formed in a topological fashion by summing all tree admittance products and appropriate 2-tree, 3-tree, ... k-tree admittance products.

In both methods, k-tree and loop-set, the solution of passive circuits is obtained as a sum of linear products of the network parameters, thus eliminating the requirement for operations with polynomials, and facilitating machine evaluation of symbolic solutions. In addition, the two methods compare favorably with respect to the number of loop-transmittance products and tree-admittance products for a given circuit, since the maximum number of trees possible for a given topology is only one greater than the maximum number of loop-sets contained in the corresponding primitive flowgraph [20]. Each tree-admittance product is unique; however, in the flowgraph method several loop-sets are frequently found to have identical transmittance product magnitudes, although only one will remain after cancellation. Thus each remaining product is unique. A primary advantage of both procedures is this feature which obviates the evaluation of zero terms, as they would be if the system determinant were evaluated by matrix algebra.

Although the two methods appear equal from the above discussion, a very important difference arises in the solution of active networks since the k-tree approach requires the graph to be modified and divided into separate current and voltage graphs from each of which the complete k-trees must determined, whereas in the loop-set analysis the procedure is invariant for passive or active networks.

Another significant disadvantage of the k-tree analysis is its dependence upon the particular transfer function to be evaluated, i.e., impedance, admittance, gain, etc., each requiring different types of k-tree searches. Thus, the number of k-tree searches will vary with the number of transfer functions as well as the type desired. Therefore, the flowgraph

method appears to have a distinct advantage in this respect, since the procedure remains identical regardless of the number or types of transfer functions. For these reasons the flowgraph approach was chosen for implementation in NASAP.

D. SUMMARY

It was the objective of this study to determine the feasibility of utilizing the loop-set symbolic form of the transfer function originated in the manner described in (B) above as a basis for computing and storing sensitivity information in similar symbolic form, thereby vastly simplifying the repetitive computation of accurate network sensitivities and rendering such solutions free of the difficulties involved with differential, or numerical techniques.

II. DEVELOPMENTAL PROCEDURE

Utilizing the revised version of NASAP developed for the PDP-10 and CDC-3300 computers by R. S. Schwartz [20], adaptation to the IBM 360/67 computer at the Naval Postgraduate School, Monterey was accomplished by: (1) altering program statements necessary to reconcile the difference in word lengths between the two types of computers, (2) making various syntax changes necessitated by technical differences in the implementation of FORTRAN on the different machines, and (3) changing the modular form and adding program statements necessary to provide for the execution of the algorithm as intended by the author. Details of the conversion are apparent from comparison of the program listing available at the W. R. Church Computer Center, USNPGS, Monterey, California with that of Ref. 20. The listing found in the appendix of this thesis contains only the NAS1, NAS4, and SENS subroutines. The first two are included since extensive modifications were incorporated in the course of implementing the sensitivity feature, and the latter because it is entirely new.

As previously described, the NASAP program has available, in symbolic form, the uncancelled loop products created from a topological flowgraph analysis of a given circuit. It was from this base that the writer devised a program to compute circuit transfer function sensitivities in an algorithm developed as follows.

Since, in subroutine NAS4 of the original program, there implicitly exists a requested transfer function,

$$T(s) = K \frac{N(s)}{D(s)} \text{ in which,}$$

$$N(s) = b_0 s^n + b_1 s^m + \ldots + b_i s^p + \ldots + b_{LPN} s^q$$

$$D(s) = a_0 s^{n'} + a_1 s^{m'} + \ldots + a_i s^{p'} + \ldots + a_{LPD} s^{q'}$$

where n, m, p, q, n',m', p', q', ... are integer exponents of the Laplace variable s, not sorted into any ascending or descending order and with repetitions possible; and where a_i, b_i represent the i^{th} loop products (algebraic product/quotients of circuit parameters in symbolic form); and where LPD is the number of uncancelled loop products in the denominator polynomial of T(s) and LPN the number in the numerator. Each loop product is actually determined from one 32-bit computer word, wherein the presence (1) or absence (0) of each element is indicated by the corresponding bit value. This, of course limits the number of circuit parameters which can be accommodated by the program to NBITS-1 = 31, although in the current version this upper limit is set to 23 due to other considerations.

It was desired, then, to compute the sensitivity of T(s) in symbolic form, to a specified circuit parameter P_k. Since sensitivity is essentially a rate-of-change, it follows that the transfer function sensitivity may be defined as:

$$S_{P_k}^{T} = \frac{\partial T(s)}{\partial P_k} = \frac{\partial (N(s)/D(s))}{\partial P_k} = \frac{D(s).\frac{\partial N(s)}{\partial P_k} - N(s).\frac{\partial D(s)}{\partial P_k}}{D^2(s)} \qquad (1)$$

To implement this fundamental approach utilizing the data available in NAS4, the following simple algorithm was developed, (See Flow-Chart, Fig. 1):

(I) Observe the j^{th} factor of the i^{th} loop product, b_{ij}, in the numerator of T.

Is b_{ij} in the numerator of the i^{th} loop product, b_i?

YES: (a) Is this factor the parameter P_k?

YES: (i) Set flag to indicate that b_i contains P_k.

(ii) Form: $\left(\frac{\partial N}{\partial P_k}\right)_{ij} = 1$

NO: Form: $\left(\frac{\partial N}{\partial P_k}\right)_{ij} = b_{ij}$

(b) $N_{ij} = b_{ij}$

NO: (a) Is this factor P_k?

YES: (i) Set flag

(ii) Change sign of $\left(\frac{\partial N}{\partial P_k}\right)_i$

(iii) Form: $\left(\frac{\partial N}{\partial P_k}\right)_{ij} = 1/(b_{ij})^2$

NO: Form $\left(\frac{\partial N}{\partial P_k}\right)_{ij} = 1/b_{ij}$

(b) $N_{ij} = 1/b_{ij}$

(II) Repeat step (I) for the $(j+1)^{th}$ factor of the i^{th} loop product. Continue until all factors are exhausted (j>NFN(i), where NFN(i) represents the number of factors in the i^{th} loop product of the numerator polynomial).

(III) Does $\left(\frac{\partial N}{\partial P_k}\right)_i$ contain P_k? (is flag set to 1?)

YES: Continue

NO: Set $\left(\frac{\partial N}{\partial P_k}\right)_i = 0$

IV) (A) i = i + 1

(B) Repeat (I) (II), and (III) for the $(i+1)^{th}$ loop product. Continue until all loops are exhausted (i>LPN).

(V) Repeat the entire procedure beginning with step (I) for the denominator of T(s).

At this point the sensitivity is implicitly available in the desired form (eqn. 1), where:

$$D = \sum_{i=1}^{LPD} \prod_{j=1}^{NFD(i)} D_{ij} \, s^{EXPDS(i)}$$

$$N = \sum_{i=1}^{LPN} \prod_{j=1}^{NFN(i)} N_{ij} s^{EXPNS(i)}$$

$$\frac{\partial D}{\partial P_k} = \sum_{i=1}^{LPD} \prod_{j=1}^{NFD(i)} \left(\frac{\partial N}{\partial P_k} \right)_{ij} s^{EXPDS(i)}$$

$$\frac{\partial N}{\partial P_k} \sum_{i=1}^{LPN} \prod_{j=1}^{NFN(i)} \left(\frac{\partial N}{\partial P_k} \right)_{ij} s^{EXPNS(i)}$$

NFN(i) = Number of factors in the i^{th} loop product of numerator polynomial

NFD(i) = Number of factors in the i^{th} loop product of denominator

EXPNS(i) = Exponent of $\underline{s}$ in the i^{th} loop product of numerator

EXPDS(i) = Exponent of $\underline{s}$ in the i^{th} loop product of denominator

One feature of the programming which became necessary in order to reduce storage requirements for the symbolic sensitivity component variables SNUM, SDEN, PARTLN, and PARTLD was a packing scheme which in effect reduced vector sizes by a factor of one-fourth. In the NASAP program, as in most FORTRAN programs, each alphanumeric character is represented by a four-byte word, wasting a great deal of core storage since one byte is sufficient for one character. This exemplifies one of the most unattractive aspects of the FORTRAN language, especially when dealing with character strings or literals as in the case of the NASAP symbolic version.

A remedy for the problem which was utilized in this program is a very short but efficient packing subroutine which has four arguments:

(1) a four-byte variable to be "packed"

(2) an integer constant specifying the byte number of the variable in (1) to be assigned the value of the packing variable

(3) packing variable

(4) an integer constant specifying the byte number of the variable in (3) which is to be assigned to the variable in (1)

Upon calling the pack subroutine, dummy variables, locally declared LOGICAL*1 (one byte), receive data passed from the specified byte of the packing variable, assign this to the specified byte of the variable to be packed, and then return this new "packed" version to the calling program. In this manner the sensitivity component variables were packed with parameter name (e.g. L01, R04, etc.) in bytes one through three, and byte number four was packed with a code number to indicate the form in which the parameter should appear. This code appears below:

0 -- Numerator or denominator = z, partial = z

3 -- Numerator or denominator = z, partial = 1

4 -- Numerator or denominator = z, partial = 0

6 -- Numerator or denominator = 1/z, partial = 1/z

7 -- Numerator or denominator = 1/z, partial = $-1/z^2$

9 -- Numerator or denominator = 1/z, partial = 0

With this scheme the program was rendered capable of processing networks of up to 200 independent loops to provide for sensitivity with respect to a single parameter, or by successive solutions to provide for any or all sensitivities desired. With this loop-set limit, the entire program, including NASAP requires 180K of core. A guide for core storage allocation may be found in the appendix for circuits of greater complexity.

Subsequent to the packing operation, data is transferred to a new subroutine SENS for manipulation into the desired form and for numerical evaluation. In this operation it was found impractical, of course, to permit each product element to occupy a separate storage location in the computer, since this would essentially require dimensions on the order of the square of the maximum number of loop products. Therefore, numerical evaluation of the constituent components of the sensitivity are recursively computed and simultaneously combined at this point in the program to form the numerator and denominator arrays, PART1 and PART2. Eliminating all zero vectors and combining like powers of $\underline{s}$ reduced storage requirements for this operation essentially to twice the order of the denominator polynomial.

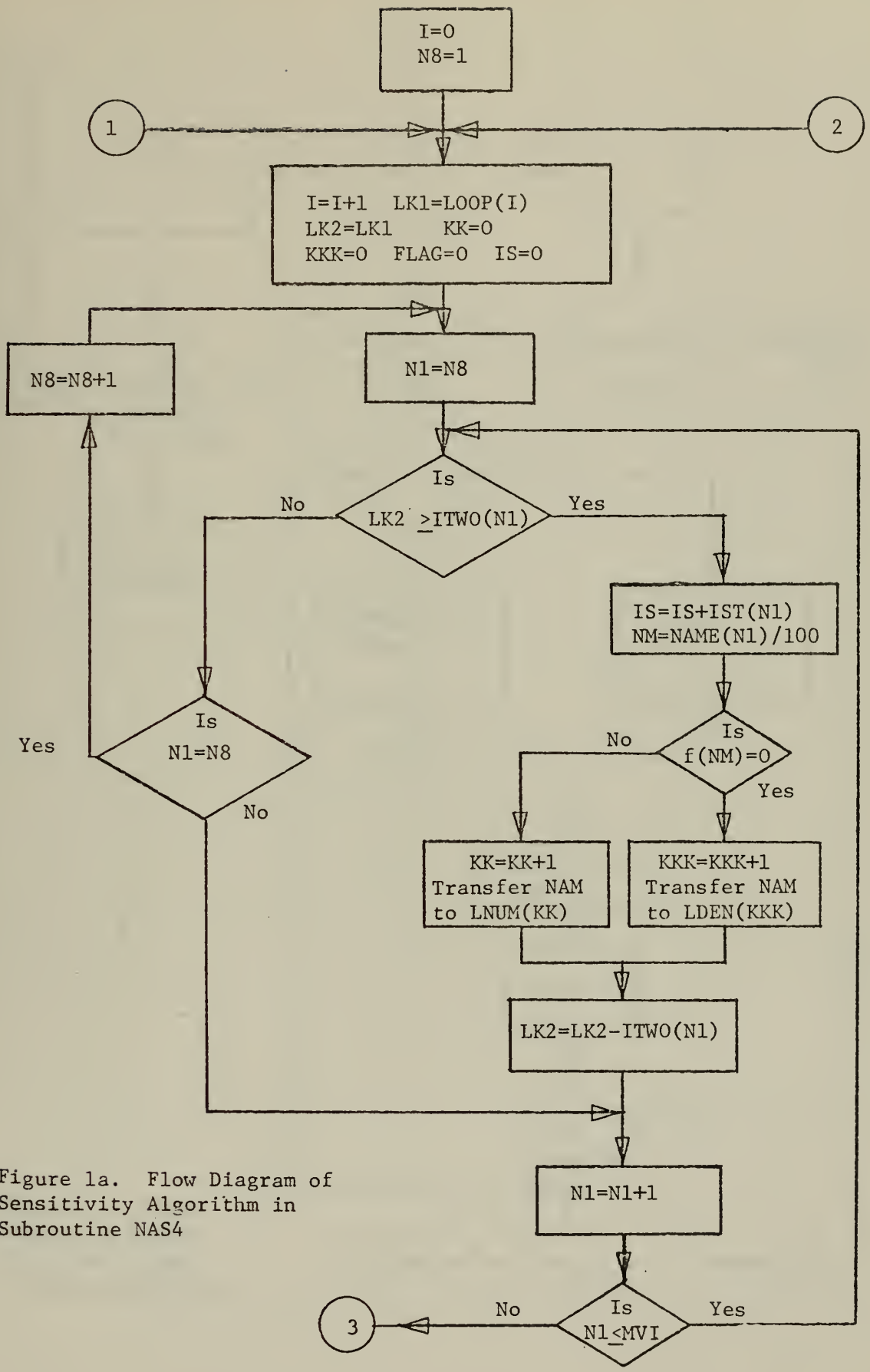


Figure 1a. Flow Diagram of Sensitivity Algorithm in Subroutine NAS4

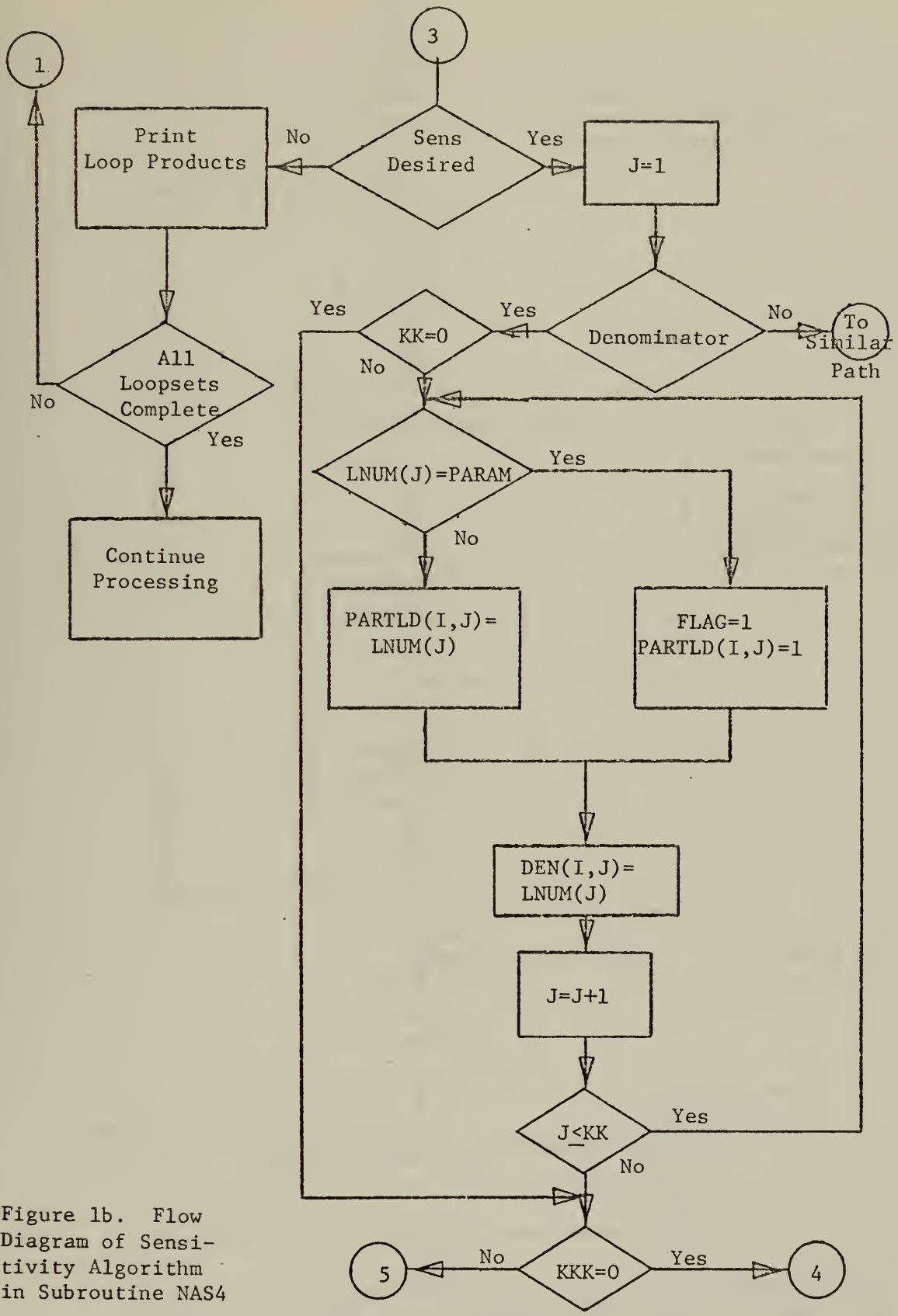


Figure 1b. Flow Diagram of Sensitivity Algorithm in Subroutine NAS4

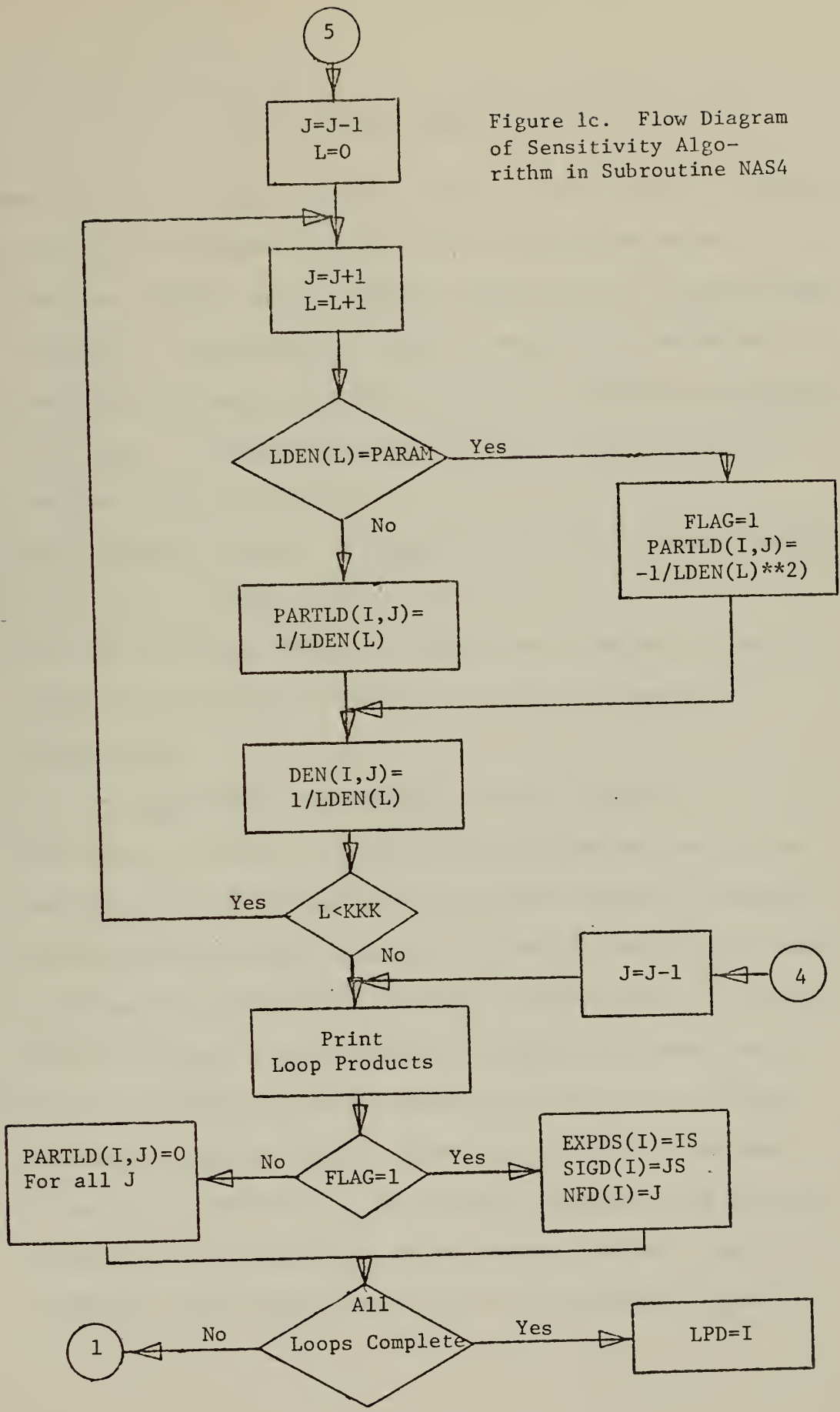


Figure 1c. Flow Diagram of Sensitivity Algorithm in Subroutine NAS4

III. USER'S RULES

Users of the sensitivity subroutine must be familiar with the simple NASAP coding rules contained in Refs. 1 and 2 as modified below:

(1) Only one "OUTPUT" and/or "ROOTS" transfer function request should be made in a given problem since the sensitivity subroutine is designed to store data relevant to only one numerator polynomial at a time. Of course, the user may wish to follow one set of problem cards with another.

(2) The "SYMBOLIC SOLUTION" card must be inserted following "EXECUTE".

(3) No "MODIFY" requests are permitted.

(4) The card following "SYMBOLIC SOLUTION" must contain the words (only the underlined portions are essential for machine recognition);

SENSITIVITY PARAMETER=L02 (or R01, C09, etc.)

Any number of blanks or identifying characters may be included so long as the underlined portions appear somewhere in columns 1-80 in the order shown. Notice that the parameter (with respect to which the sensitivity is desired) is indicated by the consecutive characters, (=), (R, L, or C), (two digit element number).

(5) If it is desired to have the sensitivity magnitude and phase evaluated, the next card in sequence must contain a maximum frequency in columns 1-11 and a minimum frequency (not zero) in columns 21-31, preferably both in standard FORTRAN formal E11.4, although normal floating-point form is satisfactory if all

significant digits (plus sign) remain within the specified 11 columns. Specifying these frequencies limits will result in a print-out of the sensitivity magnitude and phase at 200 evenly distributed frequencies in the interval.

(Caution: If the user omits this option and desires to follows the current problem deck with others, a blank card must be inserted in place of the frequency interval card).

An interested user may provide for the plotting of the generated magnitude and phase data by changing the variables RMAGN, ANGLE, and FREQ into array variables in the SENS subroutine, then passing them to an existing library plotting subroutine. This will, of course, considerably increase the core storage required for the program.

IV. INTERACTIVE APPLICATIONS

The NASAP program, in conjunction with the sensitivity subroutine, may be easily adapted for use under a time-sharing system such as CP/CMS with only a few simple statement changes which depend upon the user's choice of file structure. One choice successfully used at the Naval Postgraduate School is to remove the four initial statements: (1) CALL NASAP, (2) STOP, (3) END, and (4) SUBROUTINE NASAP. It is possible, then, to "offline read" the program into CP in the following modular form:

FILE	PROGRAM CONTENT
RSS	Program RSS (Driving program)
NAS1	NAS1, FUNCTION ITRAN
NAS2	NAS2
NAS3	NAS3
NAS4	NAS4, SUBROUTINE PACK
NAS5	NAS5
SENS	SENS, BLOCK DATA

Under CP/CMS, the entire program can then be implemented by executing "RSS", with data being input at the terminal, or if the three "READ" statements in NAS1 are changed appropriately, data may be read from a separate file so defined.

V. DISCUSSION AND RECOMMENDATIONS FOR FURTHER IMPROVEMENT

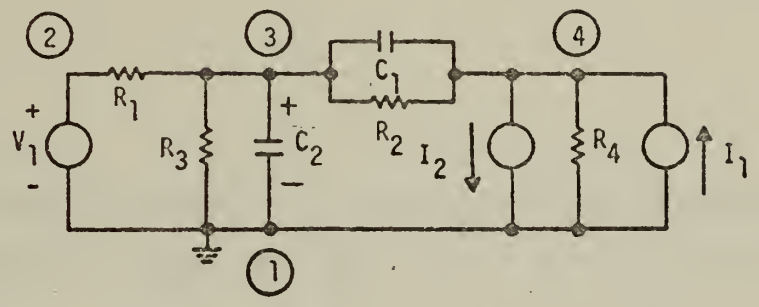
As the reader may have gathered, the feasibility of computing sensitivities of a transfer function to all circuit parameters and storing them in symbolic form appears doubtful under present storage limitations. What follows, however, is a recommendation for further reducing storage requirements somewhat while maintaining the symbolic concept. If only a single numerical sensitivity were desired, it would of course be considerably more efficient to recursively evaluate the sensitivity from successive loop-sets with their appropriate values first as given, then in partial derivative form. This procedure would eliminate most of the storage problems. The singular advantage of the symbolic approach, however, is that evaluation of the sensitivity function at various frequencies, of for various parameters, is a very simple matter of substitution, rather than the use of time-consuming iterative or numerical techniques which may pose stability or accuracy difficulties.

It is apparent that substantial changes are indicated in the proposed algorithm (or perhaps only the techniques for implementing the algorithm which will permit the sensitivity subroutine to cope with circuits of greater complexity by means of a reduction in the large storage requirements. However, it must be remembered that the resulting exponential increase in the number of independent loops with respect to a concomitant increase in the number of nodes [20] will in itself limit the complexity of topological/flowgraph methods, particularly in maximal-planar networks. Indeed, the difficulties of dimensionality plague all circuit analysis programs.

One suggested method of reducing storage requirements would be to extend the previously mentioned concept of utilizing individual bits of the computer word to represent constituent elements of the network. Since in this case it is necessary to know which of six mathematical formulations is appropriate for each element of the numerator and denominator polynomials, instead of only two formulations as in the case of transfer function loops, it would appear that a scheme requiring only three variables ($2^3 = 8$ possibilities), for a numerator and denominator each dimensioned to the maximum number of loops (10,000 in the present version) would suffice to allow sensitivities to be computed and stored in symbolic form. This would represent a substantial reduction from the 460,000 that are presently required for a 10,000-loop circuit to accomplish the same task. This suggestion, in effect, offers an execution time-vs-storage tradeoff, since a coding/decoding algorithm must be developed which will intrinsically involve a tremendous number of manipulations. In addition it would require an almost total rewrite of the FORTRAN programming, particularly that portion meshed with the NASAP NAS4 subroutine, and it may very well lead to difficulties not apparent without further investigation.

(I) Sample problem No. 1 - Emitter Follower

(a) Emitter follower linear model:



(b) NASAP coding:

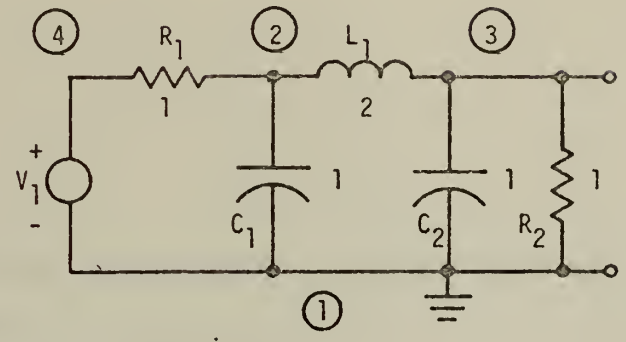
```
NASAP PROBLEM NO. 1
*EMITTER FOLLOWER
V1 1 2 1
I1 1 4 1
R1 2 3 100
R2 3 4 1M
R3 3 1 1.5K
R4 4 1 100
C1 3 4 6PF
C2 3 1 200PF
I2 4 1 0.04VC2
OUTPUT
VR4/VV1
EXECUTE
SYMBOLIC SOLUTION
SENSITIVITY PARAMETER=R04
```

(c) Sensitivity output for emitter follower:

```
NUMERATOR POLYNOMIAL : SENSITIVITY OF VR04/VV01  TO  R04
 0.6944E 40 TIMES S**  0
 0.1042E 31 TIMES S** -1
 0.6667E 17 TIMES S** -2

DENOMINATOR POLYNOMIAL :  SENSITIVITY
 0.2778E 19 TIMES S**  2
 0.3473E 31 TIMES S**  1
 0.1085E 43 TIMES S**  0
 0.1111E 30 TIMES S** -1
 0.2845E 16 TIMES S** -2
```

(II) Sample Problem No. 2 - Butterworth Filter

(a) Original linear circuit:



(b) NASAP coding:

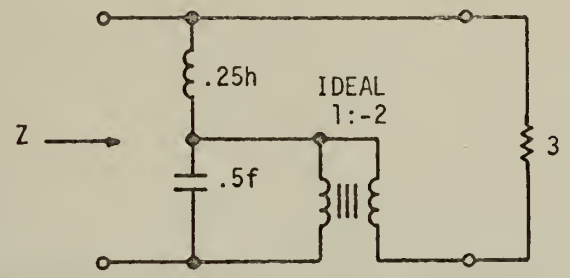
```
NASAP PROBLEM
*THIRD ORDER BUTTERWORTH
R1 4 2 1
R2 3 1 1
C1 2 1 1
L1 2 3 2
C2 3 1 1
V1 1 4 1
OUTPUT
VR2/VV1
EXECUTE
SYMBOLIC SOLUTION
SENSITIVITY PARAMETER=R02
```

(c) Sensitivity output for Sample Problem No. 2 - Butterworth Filter:

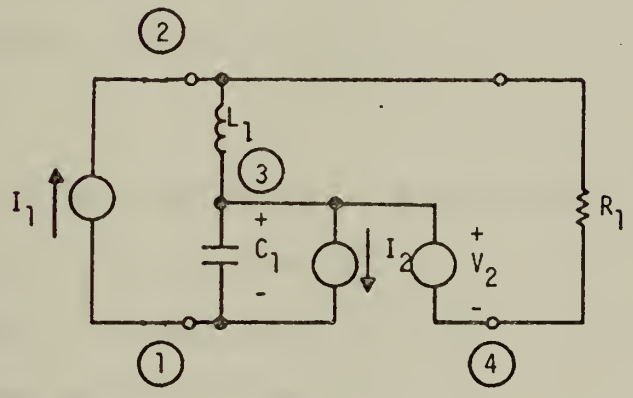
```
NUMERATOR POLYNOMIAL : SENSITIVITY OF VR02/VV01  TO  R02
 0.5000E 00 TIMES S**  0
 0.5000E 00 TIMES S** -1
 0.2500E 00 TIMES S** -2

DENOMINATOR POLYNOMIAL :  SENSITIVITY
 0.1000E 01 TIMES S**  4
 0.4000E 01 TIMES S**  3
 0.8000E 01 TIMES S**  2
 0.1000E 02 TIMES S**  1
 0.8000E 01 TIMES S**  0
 0.4000E 01 TIMES S** -1
 0.1000E 01 TIMES S** -2
```

(III) Sample Problem No. 3 - Transformer circuit

(a) Original circuit with ideal transformer:



(b) Linear model:



(c) NASAP coding:

```
NASAP PROBLEM
*INPUT IMPEDANCE
I1 1 2 1
R1 2 4 3
C1 3 1 0.5
L1 2 3 0.25
I2 3 1 -2 IR1
V2 4 3 -2 VC1
OUTPUT REQUEST
VI1/II1
EXECUTE
SYMBOLIC SOLUTION
SENSITIVITY PARAMETER=L01
  .1592E 03              .1592E 00
```

(d) Sensitivity output for Sample problem No. 3 - Transformer circuit:

```
NUMERATOR POLYNOMIAL : SENSITIVITY OF V101/I101  TO  L01
 0.1000E 01 TIMES S**  1
-0.3333E 00 TIMES S**  0
 0.2778E-01 TIMES S** -1

DENOMINATOR POLYNOMIAL :  SENSITIVITY
 0.1778E 01 TIMES S**  2
 0.2667E 01 TIMES S**  1
 0.1444E 01 TIMES S**  0
 0.3333E 00 TIMES S** -1
 0.2778E-01 TIMES S** -2
```

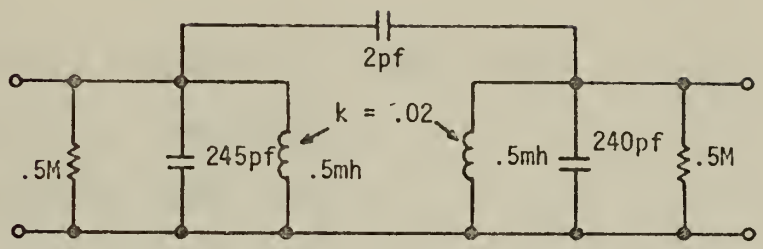
(e) Sensitivity magnitude and phase output for Sample Problem No. 3 - Transformer circuit:

EVALUATION OF SENSITIVITY

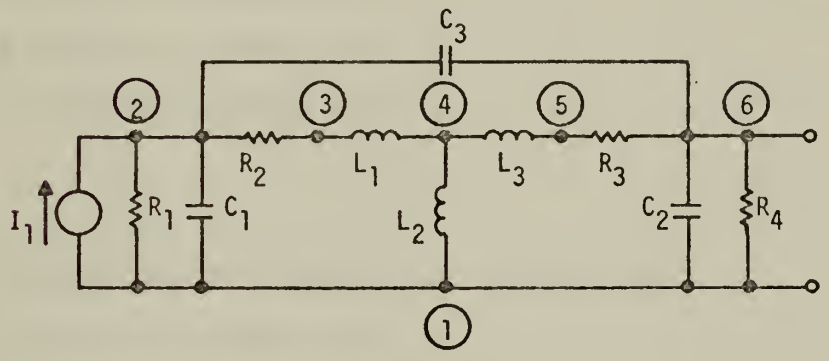
FREQUENCY	MAGNITUDE	PHASE(IN RADIANS)
0.1592E 00	0.4352E 00	0.1763E 00
0.9584E 00	0.9268E-01	-0.1267E 01
0.1758E 01	0.5082E-01	-0.1405E 01
0.2557E 01	0.3498E-01	-0.1457E 01
0.3356E 01	0.2666E-01	-0.1484E 01
0.4155E 01	0.2154E-01	-0.1501E 01
0.4954E 01	0.1806E-01	-0.1512E 01
0.5754E 01	0.1556E-01	-0.1520E 01
0.6553E 01	0.1366E-01	-0.1526E 01
0.7352E 01	0.1218E-01	-0.1531E 01
0.8151E 01	0.1098E-01	-0.1535E 01
0.8950E 01	0.1000E-01	-0.1538E 01
0.6250E 02	0.1432E-02	-0.1566E 01
0.6330E 02	0.1414E-02	-0.1566E 01
0.6409E 02	0.1397E-02	-0.1566E 01
0.6489E 02	0.1380E-02	-0.1566E 01
0.6569E 02	0.1363E-02	-0.1566E 01
0.6649E 02	0.1346E-02	-0.1566E 01
0.6729E 02	0.1330E-02	-0.1566E 01
0.6809E 02	0.1315E-02	-0.1567E 01
0.6889E 02	0.1300E-02	-0.1567E 01
0.6969E 02	0.1285E-02	-0.1567E 01
0.1480E 03	0.6049E-03	-0.1569E 01
0.1488E 03	0.6016E-03	-0.1569E 01
0.1496E 03	0.5984E-03	-0.1569E 01
0.1504E 03	0.5952E-03	-0.1569E 01
0.1512E 03	0.5921E-03	-0.1569E 01
0.1520E 03	0.5890E-03	-0.1569E 01
0.1528E 03	0.5859E-03	-0.1569E 01
0.1536E 03	0.5828E-03	-0.1569E 01
0.1544E 03	0.5798E-03	-0.1569E 01
0.1552E 03	0.5768E-03	-0.1569E 01
0.1560E 03	0.5739E-03	-0.1569E 01
0.1568E 03	0.5709E-03	-0.1569E 01
0.1576E 03	0.5680E-03	-0.1569E 01
0.1584E 03	0.5652E-03	-0.1569E 01
0.1592E 03	0.5623E-03	-0.1569E 01

(IV) Sample Problem No. 4 - I.F. Transformer

(a) I.F. Transformer circuit:



(b) Linear model:



(c) NASAP coding:

```
NASAP PROBLEM
*I.F. TRANSFORMER
I1 1 2 1
R1 2 1 .5M
C1 2 1 245PF
R2 2 3 10
L1 3 4 .49MH
L2 4 1 .01MH
L3 4 5 .49MH
R3 5 6 10
C2 6 1 240PF
C3 2 6 2 PF
R4 6 1 .5M
OUTPUT
VR4/I11
EXECUTE
SYMBOLIC SOLUTION
SENSITIVITY PARAMETER=C03
```

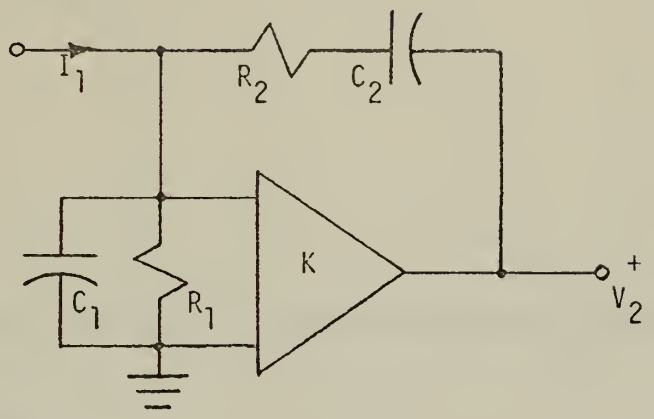
(d) Sensitivity output for Sample Problem No. 4 - I.F.

Transformer:

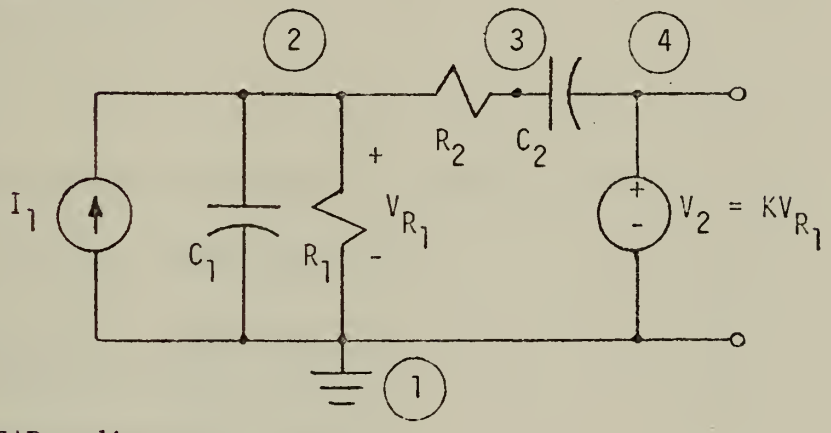
```
NUMERATOR POLYNOMIAL : SENSITIVITY OF VR04/I101  TO  C03
 0.4720E 18 TIMES S**  5
 0.4786E 16 TIMES S**  4
 0.1293E 14 TIMES S**  3
 0.4049E 10 TIMES S**  2
 0.4725E 06 TIMES S**  1
 0.2309E 02 TIMES S**  0
 0.4000E-03 TIMES S** -1

DENOMINATOR POLYNOMIAL :  SENSITIVITY
 0.4760E 42 TIMES S**  6
 0.4827E 40 TIMES S**  5
 0.1304E 38 TIMES S**  4
 0.4095E 34 TIMES S**  3
 0.4805E 30 TIMES S**  2
 0.2375E 26 TIMES S**  1
 0.4266E 21 TIMES S**  0
 0.4074E 15 TIMES S** -1
 0.1000E 09 TIMES S** -2
```

(V) Sample Problem No. 5 - Wien-Bridge circuit

(a) Original circuit:



(b) Linear model:



(c) NASAP coding:

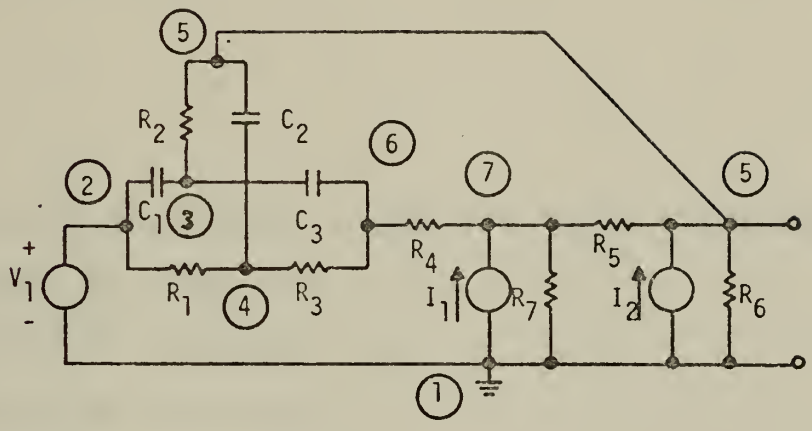
```
NASAP PROBLEM
*WIEN-BRIDGE CIRCUIT
I1 1 2 1
R1 2 1 1
C1 2 1 1
R2 2 3 1
C2 3 4 1
V2 1 4 1 VR1
OUTPUT
VV2/II1
EXECUTE
SYMBOLIC SOLUTION
SENSITIVITY PARAMETER=R02
```

(d) Sensitivity output for Sample Problem No. 5 - Wien-Bridge circuit:

```
NUMERATOR POLYNOMIAL : SENSITIVITY OF VV02/I101  TO  R02

IDENTICALLY ZERO


DENOMINATOR POLYNOMIAL :  SENSITIVITY
 0.1000E 01 TIMES S**  4
 0.4000E 01 TIMES S**  3
 0.6000E 01 TIMES S**  2
 0.4000E 01 TIMES S**  1
 0.1000E 01 TIMES S**  0
```

(VI) Sample Problem No. 6 - High-Q Filter

(a) Filter circuit:



(b) NASAP Coding:

```
NASAP PROBLEM
*HIGH - Q FILTER
V1 1 2 1
R1 2 4 20K
R2 5 3 10K
R3 6 4 20K
R4 6 7 100
R5 7 5 100
R6 5 1 2K
R7 7 1 1M
C1 2 3 .02UF
C2 5 4 .04UF
C3 6 3 .02UF
I1 1 7 150 IR4
I2 1 5 150 IR5
OUTPUT
VR6/VV1
EXECUTE
SYMBOLIC SOLUTION
SENSITIVITY PARAMETER=C02
```

(c) Sensitivity output for Sample Problem No. 6 - High-Q filter:

```
NUMERATOR POLYNOMIAL : SENSITIVITY OF VR06/VV01  TO  C02
-0.2684E 09 TIMES S**  6
 0.3125E 12 TIMES S**  5
 0.3125E 09 TIMES S**  4
 0.1031E 06 TIMES S**  3
 0.1250E 02 TIMES S**  2
 0.5000E-03 TIMES S**  1

DENOMINATOR POLYNOMIAL :  SENSITIVITY
 0.1650E 24 TIMES S**  6
 0.2869E 21 TIMES S**  5
 0.1887E 18 TIMES S**  4
 0.5643E 14 TIMES S**  3
 0.6908E 10 TIMES S**  2
 0.1575E 06 TIMES S**  1
 0.1000E 01 TIMES S**  0
```

APPENDIX B GUIDE FOR THE ALLOCATION OF CORE STORAGE

NUMBER OF LOOP-SETS POSSIBLE (VARIABLE DIMENSION)	PROGRAM CORE REQUIRED
* 200	180K
300	205K
400	230K
500	255K
600	280K
700	305K
** 800	330K
900	355K
1000	380K
*** 5000	505K
10000	630K

* Corresponds approximately to a maximal planar network of 5 nodes

** Corresponds approximately to a maximal planar network of 6 nodes

*** Corresponds approximately to a maximal planar network of 7 nodes

```
      SUBROUTINE NAS1
      INTEGER EOFCKF,SENSFL,PARAM
      DIMENSION INLST(80),NODE(21)
      COMMON/SEN/PARAM(3),SENSFL,FRMAX,FRMIN
      COMMON/DATA/INSR1(100),INSR2(24,6),ITSK1(15,4),ITSK2(3
     1,6),ITSK3
     5(15,6),ITSK4(10,5),ITSK5(9,10),IRAY(19,2),ISYMB(48),
     6ITASK6(17,12),IOPRTN(3,2)
      COMMON IND,NASA,MTRAN(3),MD,IJTAG(15,2),IPRIN,Z(42
     1),LL,MODNM(23),VALMOD(23,10),ILOOP(23),LI,LIC,M9,ZZ(23
     2),
     3NAM(23,3),ITAG(5,8),NMBR(6),
     4M,LCONC(10,40),NAME(23,2),MVI,IST(40),INC(38,42),N1,NA
     +,M2
      DATA IB/'    '/,IE/1HE/
      FRMAX=0.0
      FRMIN=0.0
   66 READ(5,101,END=998) INLST
65    DO 1 J=1,32
      IF(INLST(J)-IB)300,1,300
300   DO 2 I=1,3
      IF(INLST(J)-IOPRTN(I,1))2,350,2
350   IF(INLST(J+1)-IOPRTN(I,2))2,360,2
2     CONTINUE
      GOTO 3
360   GOTO(4,301,351),I
    1 CONTINUE
      GO TO 66
351   GO TO (67,303,352,68,68),NASA
352   IPRIN=2
      IND=4
      WRITE (6,119)
      WRITE (6,116)INLST
      READ(5,101,END=1357) INLST
      IF(INLST(1)-IOPRTN(3,1))1357,1351,1357
1351  IF(INLST(2)-IE)1357,1352,1357
1352  SENSFL=1
      DO 1353 K=3,80
      IF(INLST(K)-ISYMB(46))1353,1355,1353
1353  CONTINUE
1355  KP1=K+1
      DO 1354 I=KP1,80
      IF(INLST(I).EQ.IB) GO TO 1354
1356  PARAM(1)=INLST(I)
      DO 1360 MM=1,10
      IF(INLST(I+1).EQ.ISYMB(MM)) GO TO 1361
1360  CONTINUE
1361  PARAM(2)=MM-1
      DO 1362 MM=1,10
      IF(INLST(I+2).EQ.ISYMB(MM)) GO TO 1363
1362  CONTINUE
1363  PARAM(3)=MM-1
      READ(5,100,END=60) FRMAX,FRMIN
      GO TO 60
1354  CONTINUE
1357  SENSFL=0
      GO TO 60
  3   K=J
      GO TO (67,69,68,68,69),NASA
67    WRITE (6,119)
      WRITE (6,109)
      NASA=4
   68 WRITE (6,116)INLST
      GO TO 66
301   GO TO (67,303,305,68,68),NASA
303   WRITE (6,304)
```

```
      GOTO 68
305   K=J+1
      K1=80
      K2=6
      DO 400J=1,23
      ILOOP(J)=0
      MODNM(J)=0
      DO 400 L2=1,10
400   VALMOD(J,L2)=0.
      L1=6
      L2=1
      M9=1
      ISGN=1
      LD=0
      IZ=0
      LI1=0
      IS=1
      WRITE (6,119)
      GOTO 69
    4 NASA=2
      K1=30
      K2=0
      WRITE (6,119)
      WRITE (6,116)INLST
      DO 5 I=1,21
       Z(I)=0.
       Z(I+21)=0.
       NODE(I)=0
      DO 5 J=1,42
5     INC(I,J)=0
       MTRAN(1)=0
      MTRAN(2)=0
      MTRAN(3)=0
      MC=0
       N=0
       IPRIN=0
      M=2
      MOVFL=23
    6 ISGN=+1
      LD=0
      L1=1
      M=M+1
      IF(M-MOVFL-3) 7,96,96
    7 L2=1
      IZ=0
      GO TO 66
   69 WRITE (6,116)INLST
      DO 47 J=K,K1
      ILST=ITRAN(INLST(J))
      IF(INSR1(ILST))12,98,10
10    L3=INSR1(ILST)
      ILST=L3
      IF(INSR2(L3,L1))99,98,11
   11 L3=INSR2(L3,L1)+1
      GO TO 13
   12 L3=1
      ILST=-INSR1(ILST)-1
13    GOTO(14,15,16,17,18,308),L1
   14 L3=ITSK1(L3,L2)
      I=1
      GO TO 19
   15 L3=ITSK2(L3,L2)
      GO TO 19
   16 L3=ITSK3(L3,L2)
      GO TO 19
   17 L3=ITSK4(L3,L2)
      I=2
      GO TO 19
   18 L3=ITSK5(L3,L2)
      GOTO 19
308   L3=ITASK6(L3,L2)
   19 GO TO (20,21,21,24,26,27,28,29,30,31,33,
```

```
     +36,37,38,39,40,45,46,47,51,66,97,98,99,41,42,43,44,
     +310,311,312,313,314,316,316,319,316,316,316,316,321,
     +375),L3
   20 MN=10*MN+ILST
   21 INC(MN+1,M)=4*(L2-3)**3/((L2-3)**2+1)**2
      IF(MN-N) 23,23,22
   22 N=MN
   23 NODE(MN)=NODE(MN)+1
      GOTO(46,45,39),L3
   24 IF(ILST)99,47,25
   25 MN=ILST
      GO TO 46
   26 ISGN=-1
      GO TO 46
   27 INC(I,M)=100*ISGN*ILST
      GO TO 46
   28 INC(I,M)=INC(I,M)+ISGN*MN
      GO TO (39,46),I
   29 INC(I,M)=INC(I,M)+ISGN*(10*MN+ILST)
      GO TO 46
   30 LD=LD+1
   31 IZ=10*IZ+ISGN*ILST
      IF(ILST)99,47,32
32    L2=L2+(120+(L2-K2)*(2-(L2-K2)*6))/36
      GOTO 47
   33 IF(INC(1,M)/100-4) 34,35,34
   34 LD=LD+15+(ILST-10)*(582-(ILST-10)*(40+(ILST-10)*(22)))
     1/100
   35 LD=LD+3-ILST
      IF(L1-6)322,315,99
322   L2=6
      GOTO 47
   36 L1=4
      L2=1
      ISGN=(4-ILST)/3
      IF(((INC(1,M)/100)-4)/3)46,98,46
   37 ISGN=(4-ILST)/3
      MC=MC+1
      MTRAN(MT)=MD
      MD=MC/2
      ME=MC-2*MD+1
      GOTO 46
   38 L1=5
      M2=M-1
      MC=1
      MT=1
      GOTO 7
   39 L1=L1+1
      L2=1
      GOTO 47
375   WRITE (6,376)
      NASA=5
   40 JC=MC-2*MD+1
      IJTAG(MD,JC)=100*ISGN*ILST
      GOTO 46
   41 JC=MC-2*MD+1
      IJTAG(MD,JC)=IJTAG(MD,JC)+ISGN*MN
      GOTO (45,46),ME
   42 JC=MC-2*MD+1
      IJTAG(MD,JC)=IJTAG(MD,JC)+ISGN*(10*MN+ILST)
      GOTO 46
   43 MT=2
      MTRAN(2)=MTRAN(1)
      GOTO 7
   44 MT=3
      MTRAN(3)=MTRAN(1)
      GOTO 7
310   IS=-2
      GOTO(45,46),L2
311   MODNM(M9)=100*ILST
      LI=1
      L2=4
```

```
      GOTO 47
312   MODNM(M9)=MODNM(M9)+10*MN+ILST
      GOTO 46
313   MODNM(M9)=MODNM(M9)+MN
      GOTO 45
319   IS=IS+1
      IF(IS*LI+3)99,315,324
314   IF(LI-10)315,315,326
315   V=FLOAT(IZ)
      VALMOD(M9,LI)=V/10.0**(LD)
      L2=12
      IF(IS)331,99,332
331   IF(LI-3)47,334,324
334   IF(L3-36)47,340,47
340   ILOOP(M9)=(VALMOD(M9,1)-VALMOD(M9,2))/VALMOD(M9,3)-1.0
     10001
      IF(ILOOP(M9))333,328,328
332   ILOOP(M9)=LI
333   IF(LI1-IABS(ILOOP(M9)))335,47,47
335   LI1=IABS(ILOOP(M9))
      GOTO 47
316   IZ=0
      LD=0
      ISGN=1
      IF(L3-35)317,317,323
323   LI=LI+1
      L2=7
      L3=L3-36
      GOTO(31,26,45,47),L3
317   IF(IABS(IS)-1)99,338,324
338   IS=1
      L3=L3-33
      GOTO(320,337),L3
320   IS=-2
      L2=3
337   M9=M9+1
      IF(M9-M)339,339,326
339   GOTO(47,311),L3
321   IF(MODNM(M9)/100-4)34,35,34
  45  L2=L2+1
  46  L2=L2+1
  47  CONTINUE
      IF(L1-6)330,336,99
336   LI=LI1
      IND=4
      IF(IABS(IS)-1)99,60,324
330   IF((10*L1+L2)/11-3)98,48,49
  48  INC(2,M)=0
  49  I=1
      IF(L1-5)50,7,99
  50  Z(M)=FLOAT(IZ)
      Z(M)=Z(M)/10.0**(LD)
      GOTO 6
  51  N1=N+1
      IF(MTRAN(1)) 99,95,202
202   IF(INLST(J+8)-ISYMB(26))204,52,204
204   IF(INLST(J+8)-ISYMB(13))55,201,55
201   DO 203 J=1,2
      DO 200 I=1,19
      K=IRAY(I,J)
200   IRAY(I,J)=ISYMB(K)
203   WRITE (6,116)(IRAY(I,J),I=1,19)
  52  IPRIN=1
  55  NA=0
      DO 58 I=1,N,1
      IF(NODE(I)-1) 58,56,57
  56  WRITE (6,112) I
  57  NA=NA+1
      NODE(NA)=I
  58  CONTINUE
      IF(NASA-2)70,71,70
 70   NASA=4
```

```
      GO TO 66
 71   NASA=3
      IND=2
      IF(N-NA) 99,60,59
  59  WRITE (6,111) (NODE(I), I=1,NA,1)
      WRITE (6,110)
      GO TO 60
91    IND=7
  60  RETURN
  95  WRITE (6,115)
      GO TO 90
  96  WRITE (6,114) MOVFL
 90   NASA=4
      GOTO 66
  97  WRITE (6,106)
      WRITE (6,116) INLST
 72   NASA=5
      GO TO 49
  98  WRITE (6,108) J
      WRITE (6,116) INLST
      IF(L1-6)72,66,99
  99  WRITE (6,107)
      GO TO 90
326   WRITE (6,327)
      GOTO 66
328   WRITE (6,329)
324   WRITE (6,325)
      GOTO 66
100   FORMAT(E11.3,9X,E11.4)
101   FORMAT(80A1)
 106  FORMAT(24H FUNCTIONS NOT AVAILABLE)
 107  FORMAT(27H MACHINE LANGUAGE BREAKDOWN)
 108  FORMAT(32H    INPUT CODING ERROR IN COLUMN,I3)
 109  FORMAT(39H  USE HEADING LABELED     NASAP PROBLEM)
 110  FORMAT(/,1X,39HTHE ANALYSIS WILL CONTINUE ON THE ASSUM
     1,5HPTION,
     2   26H THAT THE LIST IS CORRECT.,/,1X,13HHOWEVER, SKIP
     3,9HPING NODE,
     4   39H NUMBERS IS NOT A RECOMMENDED PRACTICE.//)
 111  FORMAT(1X,41HTHE FOLLOWING NODE NUMBERS ARE MENTIONED
     1,6HIN THE,
     212H INPUT LIST ,/,1X,I2,19(1H,,I2,1X))
 112  FORMAT(//,1X,5HNODE ,I2,27H HAS ONLY ONE ELEMENT CONNE
     111HCTED TO IT.,//)
 114  FORMAT(1X,12HNO MORE THAN,I3,18H ELEMENTS ALLOWED.)
 115  FORMAT(1X,24HTHERE IS NO OUTPUT LIST.)
116   FORMAT(1X,80A1)
 117  FORMAT(1X,11I6)
119   FORMAT(1H1)
304   FORMAT(//1X,39HMODIFY AND SYMBOLIC SOLUTION MUST FOLLO
     1,9HW EXECUTE//)
325   FORMAT(//1X,39HFOR LOOPS YOU MUST SPECIFY--(START,END,
     1,4HINC))
327   FORMAT(//1X,39HTOO MANY ELEMENTS OR VALUES IN MODIFY S
     1,8HTATEMENT)
329   FORMAT(//1X,39HSTART GREATER THAN END AND/OR INC TOO L
     1,4HARGE)
376   FORMAT (/1X,27HTHE TRANSFER FUNCTION INPUT/
     +1X,33HVARIABLE IS A DEPENDENT QUANTITY.)
 998  STOP
      END


      FUNCTION ITRAN(I)
      ITRAN=1+I/16777216
      IF(ITRAN)1,2,3
    1 ITRAN=ITRAN+63
      RETURN
    3 ITRAN=ITRAN-31
      RETURN
    2 WRITE(6,4)
```

```
      RETURN
4     FORMAT(//1X,15HMACHINE FAILURE)
      STOP
      END



      SUBROUTINE NAS4
      INTEGER SENSFL,FLAG,EXPNS,SIGN,WHERE,EXPDS,SIGD,
     1PARAM,PARTLN,PARTLD
      DIMENSION JZ(5),AZ(5),LNUM(23,3),LDEN(23,3),ILGTH(23),
     1IFMT1(18),IFMT2(12)
      COMMON/SEN/PARAM(3),SENSFL,FRMAX,FRMIN
      COMMON IND,NASA,MTRN1,MTRN2,MTRN3,MD,IJTAG(15,2),I
     1PRIN,Z(42),LL,MODNM(23),VALMOD(23,10),ILOOP(23),LI,LIC
     2,M9,ZZ(23),NAM(23,3),ITAG(5,8),NMBR(6),
     3M,SNUM(30,5),SDEN(30),IOD(30),IO(5),NUM(5)
     5,XG(5),IP(30,5),ID,NUMZ,DMY(23)
     4,NAME(23,2),MVI,IST(40),LIM(6),ITWO(23),LOOP(10000)
     6,WHERE,PARTLN(200,23),EXPNS
     7(200),NFN(200),PARTLD(200,23),EXPDS(200),
     8SIGD(200),NFD(200),LPN,LPD,SIGN(200)
      DATA ILGTH/1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,2H10,
     12H11,2H12,2H13,2H14,2H15,2H16,2H17,2H18,2H19,2H20,2H21
     2,2H22,2H23/
      DATA IFMT1/4H(1X,,4HI5,I,4H8,3X,4H,A1,,4H1H(,,1H1,
     14H(A1,,1H2,4HI1),,4H3H /,2H ,,1H1,4H(A1,,4H2I1),
     24H,6H),4H S *,4H*,I3,1H)/
      DATA IFMT2/4H(1X,,4HI5,I,4H8,3X,4H,A1,,4H1H(,,1H1,
     14H(A1,,1H2,4HI1),,4H6H) ,4HS **,4H,I3)/
      DATA IM/'-   '/,IB/'    '/,IAOC/'A1, '/,ITW/'2   '/
      MDD=MTRN1+1
      IF(IPRIN-1)1,1,23
1     IERR=0
      IF(LIC)60,2,5
2     DO 3 N1=1,MVI
3     ZZ(N1)=Z(N1)
      IF(ILOOP(1)-1000)5,16,60
16    DO 19 N1=1,MTRN1
      DO 19 L=1,2
19    IJTAG(N1,L)=IJTAG(N1,L)-1000*(IJTAG(N1,L)/1000)
      IF(IPRIN)60,13,23
23    I=0
      LPN=0
      DO 1024 K2=1,MDD
      N7=LIM(K2)
      WHERE=0
      IF(K2-MDD)50,51,60
50    WRITE (6,135) (ITAG(K2,K),K=1,8)
      WRITE (6,160)
      J=-1
      IF(NMBR(K2))601,52,600
 600  JS=IM
      GOTO 602
 601  JS=IB
602   WRITE (6,162) JS
      GOTO 52
51    WRITE (6,138)
      WRITE (6,160)
      JS=IB
      WRITE (6,162) JS
      SIGD(1)=JS
      NFD(1)=1
      LPD=1
      J=1
52    N8=1
      IF(N7)60,55,56
55    WRITE (6,100)
      WRITE (6,141)
      GO TO 1024
56    DO 24 N9=1,N7
```

```
      FLAG=0
      KK=0
      KKK=0
      ISLOP=0
      JS=IB
      I=I+1
      LK1=LOOP(I)
      LK2=IABS(LK1)
      IF(J*LK1)44,60,25
 44   JS=IM
25    N1=N8
26    IF(LK2-ITWO(N1))27,28,28
27    IF(N1-N8)60,30,29
30    N8=N8+1
      GOTO 25
28    ISLOP=ISLOP+IST(N1)
      NM=NAME(N1,1)/100
      IF((NM+3)*(NM-4)*(NM-5))32,31,32
31    KKK=KKK+1
      DO 230 K=1,3
230   LDEN(KKK,K)=NAM(N1,K)
      GO TO 33
32    KK=KK+1
      DO 231 K=1,3
231   LNUM(KK,K)=NAM(N1,K)
33    LK2=LK2-ITWO(N1)
29    N1=N1+1
      IF(N1-MVI-1)26,499,60
499   IF(SENSFL-1) 34,500,60
500   JJ=1
502   IF(K2-MDD)509,799,60
509   LPN=LPN+1
      IF(LPN.GT.200) WRITE(6,164)
      IF(KK.EQ.0) GO TO 531
510   JJJ=1
      DO 511 K=1,3
      IF(K.GT.1) JJJ=4
      CALL PACK(PARTLN(LPN,JJ),K,LNUM(JJ,K),JJJ)
511   CONTINUE
      IF(LNUM(JJ,1).EQ.PARAM(1).AND.LNUM(JJ,2).EQ.PARAM(2).A
     1ND.LNUM(JJ,3).EQ.PARAM(3)) GO TO 519
      CALL PACK(PARTLN(LPN,JJ),4,0,4)
      GO TO 530
519   FLAG=1
      CALL PACK(PARTLN(LPN,JJ),4,3,4)
530   JJ=JJ+1
      IF(JJ-KK-1)510,531,60
531   IF(KKK.EQ.0) GO TO 554
      LX=0
      JJ=JJ-1
534   JJ=JJ+1
      LX=LX+1
      JJJ=1
      DO 532 K=1,3
      IF(K.GT.1) JJJ=4
      CALL PACK(PARTLN(LPN,JJ),K,LDEN(LX,K),JJJ)
532   CONTINUE
533   IF(LDEN(LX,1).EQ.PARAM(1).AND.LDEN(LX,2).EQ.PARAM(2).A
     1ND.LDEN(LX,3).EQ.PARAM(3)) GO TO 540
      CALL PACK(PARTLN(LPN,JJ),4,6,4)
      GO TO 542
540   FLAG=1
      CALL PACK(PARTLN(LPN,JJ),4,7,4)
542   IF(LX-KKK)534,555,60
554   JJ=JJ-1
555   WHERE=1
      GO TO 34
799   LPD=LPD+1
      IF(LPD.GT.200) WRITE(6,164)
      IF(KK.EQ.0) GO TO 831
800   JJJ=1
      DO 812 K=1,3
```

```
      IF(K.GT.1) JJJ=4
      CALL PACK(PARTLD(LPD,JJ),K,LNUM(JJ,K),JJJ)
812   CONTINUE
      IF(LNUM(JJ,1).EQ.PARAM(1).AND.LNUM(JJ,2).EQ.PARAM(2).A
     1ND.LNUM(JJ,3).EQ.PARAM(3)) GO TO 819
      CALL PACK(PARTLD(LPD,JJ),4,0,4)
      GO TO 830
819   FLAG=1
      CALL PACK(PARTLD(LPD,JJ),4,3,4)
830   JJ=JJ+1
      IF(JJ-KK-1)800,831,60
831   IF(KKK.EQ.0) GO TO 854
      LX=0
      JJ=JJ-1
834   JJ=JJ+1
      LX=LX+1
      DO 832 K=1,3
      JJJ=1
      IF(K.GT.1) JJJ=4
      CALL PACK(PARTLD(LPD,JJ),K,LDEN(LX,K),JJJ)
832   CONTINUE
833   IF(LDEN(LX,1).EQ.PARAM(1).AND.LDEN(LX,2).EQ.PARAM(2).A
     1ND.LDEN(LX,3).EQ.PARAM(3)) GO TO 840
      CALL PACK(PARTLD(LPD,JJ),4,6,4)
      GO TO 842
840   FLAG=1
      CALL PACK(PARTLD(I,JJ),4,7,4)
842   IF(LX-KKK)834,855,60
854   JJ=JJ-1
855   WHERE=2
 34   IF(KK)60,42,43
 42   KK=1
      LNUM(1,1)=IB
      LNUM(1,2)=IB
      LNUM(1,3)=1
      IFMT1(8)=IAOC
 43   IF(KKK)60,40,41
 40   IFMT2(6)=ILGTH(KK)
      WRITE(6,IFMT2)I,LK1,JS,((LNUM(K,K1),K1=1,3),K=1,KK),IS
     1LOP
      GO TO 901
 41   IFMT1(6)=ILGTH(KK)
      IFMT1(12)=ILGTH(KKK)
      WRITE(6,IFMT1)I,LK1,JS,((LNUM(K,K1),K1=1,3),K=1,KK),((
     1LDEN(K,K1),K1=1,3),K=1,KKK),ISLOP
      IF(IFMT1(8)-ITW)232,901,232
232   IFMT1(8)=ITW
901   IF(WHERE-1)24,902,904
902   EXPNS(LPN)=ISLOP
      SIGN(LPN)=JS
      NFN(LPN)=JJ
      IF(FLAG)60,905,932
904   EXPDS(LPD)=ISLOP
      SIGD(LPD)=JS
      NFD(LPD)=JJ
      IF(FLAG)60,908,932
905   DO 906 K=1,JJ
      ITEST=0
      CALL PACK(ITEST,4,PARTLN(LPN,K),4)
      IF(ITEST-5)960,60,961
960   CALL PACK(PARTLN(LPN,K),4,4,4)
      GO TO 906
961   CALL PACK(PARTLN(LPN,K),4,9,4)
906   CONTINUE
      GO TO 932
908   DO 931 K=1,JJ
      ITEST=0
      CALL PACK(ITEST,4,PARTLD(LPD,K),4)
      IF(ITEST-5)962,60,963
962   CALL PACK(PARTLD(LPD,K),4,4,4)
      GO TO 931
963   CALL PACK(PARTLD(LPD,K),4,9,4)
```

```
931   CONTINUE
932   IF(N9.EQ.N7) GO TO 909
      GO TO 24
909   IF(WHERE-1)24,930,930
930   CALL SENS
 24   CONTINUE
1024  CONTINUE
      IPRIN=IPRIN-1
      IF(IPRIN)13,13,89
5     LIC=LIC+1
      WRITE (6,163)
      DO 12 N1=1,M9
      IF(LIC-IABS(ILOOP(N1)))4,4,12
4     DO 11 N7=1,MVI
      IF(MODNM(N1)-IABS(NAME(N7,1)))11,6,11
6     IF(ILOOP(N1))8,60,7
7     ZZ(N7)=VALMOD(N1,LIC)
      GOTO 9
8     ZZ(N7)=VALMOD(N1,1)+FLOAT(LIC-1)*VALMOD(N1,3)
9     NM=NAME(N7,1)/100
      WRITE (6,129) (NAM(N7,K),K=1,3),ZZ(N7)
      IF((NM+3)*(NM-4)*(NM-5))12,10,12
10    ZZ(N7)=1./ZZ(N7)
      GOTO 12
11    CONTINUE
      WRITE (6,130)
      IERR=1
      MVI1=MVI+1
      DO 15 N7=MVI1,M
      IF(MODNM(N1)-IABS(NAME(N7,1)))15,14,15
14    WRITE (6,133) MODNM(N1)
      GOTO 12
15    CONTINUE
      WRITE (6,132) MODNM(N1)
12    CONTINUE
      IF(IERR)60,13,66
13    IF(ILOOP(1)-1000)17,18,60
18    WRITE (6,101)
17    DO 400 N1=1,30
      SDEN(N1)=0.
      DO 400 K2=1,MTRN1
400   SNUM(N1,K2)=0.
      DO 603 K2=1,MTRN1
603   SNUM(16,K2)=NMBR(K2)
      SDEN(16)=1.
      I=0
      DO 1412 K2=1,MDD
      N8=1
      N7=LIM(K2)
      IF(N7)60,1412,397
397   DO 412 N9=1,N7
      I=I+1
      ISLOP=0
      VLOOP=1.
      LK1=LOOP(I)
      LK2=IABS(LK1)
      SGN=LK1/LK2
401   N1=N8
402   IF(LK2-ITWO(N1)) 403,405,405
403   IF(N1-N8)60,404,406
404   N8=N8+1
      GOTO 401
405   ISLOP=ISLOP+IST(N1)
      VLOOP=VLOOP*ZZ(N1)
      LK2=LK2-ITWO(N1)
406   N1=N1+1
      IF(N1-MVI-1)402,407,60
407   JS=16-ISLOP
      IF(MDD-K2) 60,410,408
408   SNUM(JS,K2)=SNUM(JS,K2)+VLOOP*SGN
      GOTO 412
410   SDEN(JS)=SDEN(JS)+VLOOP*SGN
```

```
412   CONTINUE
1412  CONTINUE
      DO 69 K=1,MTRN1
      JZ(K)=1
      AZ(K)=0.
      DO 68 J=1,30
      IF(SNUM(J,K))67,68,67
67    IF(AZ(K))201,202,201
202   AZ(K)=-SNUM(J,K)
 201  JZ(K)=J
  68  CONTINUE
  69  CONTINUE
      SIGNC=0.
      JI=0
      DO 71 J=1,30
      IF(SDEN(J))97,71,97
  97  IF(SIGNC)70,98,70
  98  SIGNC=SDEN(J)
  70  JI=J
  71  CONTINUE
      J=0
      DO  73 K=1,MTRN1
      IF(JZ(K)-J) 73,73,72
  72  J=JZ(K)
  73  CONTINUE
      IF(JI-J)  75,75,74
  74  J=JI
75    DO 83 K=1,MTRN1
      XG(K)=0.
      IF(SIGNC)90,91,90
90    XG(K)=AZ(K)/SIGNC
  91  WRITE (6,136) XG(K)
      WRITE (6,135) (ITAG(K,I),I=1,8)
      NU=0
      IO(K)=0
      DO  82 L=1,J
      ANUM=NU
      IF(ABS(SNUM(L,K))*(ANUM-.5))80,82,81
  80  IO(K)=J-L
  81  NU=NU+1
      IP(NU,K)=J-L
      SNUM(NU,K)=-SNUM(L,K)/AZ(K)
      WRITE (6,137) SNUM(NU,K),IP(NU,K)
  82  CONTINUE
      NUM(K)=NU
      IF(NUM(K)) 60,92,83
  92  NUM(K)=1
      WRITE (6,137)  SNUM(1,K),IP(1,K)
      WRITE (6,141)
  83  CONTINUE
      WRITE (6,138)
      NUMZ=0
      ID=0
      DO  86 K=1,J
      ANUM=NUMZ
      IF(ABS(SDEN(K))*(ANUM-.5))84,86,85
  84  ID=J-K
  85  NUMZ=NUMZ+1
      IOD(NUMZ)=J-K
      SDEN(NUMZ)=SDEN(K)/SIGNC
      WRITE (6,137) SDEN(NUMZ),IOD(NUMZ)
  86  CONTINUE
      IF(NUMZ) 60,94,87
  94  NUMZ=1
      WRITE (6,137)  SDEN(1),IOD(1)
      WRITE (6,141)
87    IF(LI-LIC)150,150,152
150   LIC=0
152   IF(MTRN1-MTRN2)96,96,95
95    IF(MTRN1-MTRN3)88,88,153
153   IF(LIC)60,89,5
96    IND=5
```

```
      GO TO 900
   88 IND=6
      GO TO 900
   60 WRITE (6,134)
   66 LIC=0
   89 IND=1
  900 RETURN
  100 FORMAT(//1X,16HIDENTICALLY ZERO)
  101 FORMAT(///1X,16HNOMINAL SOLUTION)
  129 FORMAT(/1X,10HMODIFYING ,A1,2I1,4H TO ,E11.4)
  130 FORMAT(//1X,26HERROR IN ATTEMPT TO MODIFY)
  132 FORMAT(1X,12HBRANCH CODED,I5,22H--NOT IN ORIGINAL NETW
     1,3HORK)
  133 FORMAT(1X,12HBRANCH CODED,I5,22H--CANNOT MODIFY INDEPE
     1,13HNDENT SOURCES)
  134 FORMAT(//1X,24HMACHINE LANGUAGE FAILURE)
  135 FORMAT(/1X,24HNUMERATOR POLYNOMIAL OF ,2A1,2I1,1H/,2A1
     1,2I1)
  136 FORMAT(//1X,4HK = ,E11.4)
  137 FORMAT(1X,E11.4,10H TIMES S**,I3)
  138 FORMAT(//1X,22HDENOMINATOR POLYNOMIAL)
  141 FORMAT(/,1X,31HCHECK YOUR CIRCUIT CODING LIST.,
     +/,1X,26HTHIS ANSWER IS DEGENERATE.)
  160 FORMAT(/3X,28HLOC   CODE      LOOP PRODUCT)
  162 FORMAT(17X,A1,13H( 1 ) S **  0)
  163 FORMAT(/)
  164 FORMAT(' ','WARNING: NUMBER OF UNCANCELLED LOOP PRODU'
     1,'CTS EXCEEDS STORAGE AVAILABLE (200). ',/' ','YOU MU'
     2,'ST CHANGE DIMENSION STATEMENTS IN NAS4 AND SENS SUB'
     3,'ROUTINES FOR VARIABLES - ',//' ','PARTLN,EXPNS, NFN'
     4,',PARTLD,EXPDS,SIGD,NFD,SIGN,RNUMP,RNUMS,RDENS,RDENP'
     5)
      STOP
      END

C  PACKING SUBROUTINE

      SUBROUTINE PACK(A,I,B,J)
      LOGICAL*1 A(1),B(1)
      A(I)=B(J)
      RETURN
      END



      SUBROUTINE SENS
      COMPLEX*8 CFREQ,CTEMP,CTEMP1,CTEMPB
      INTEGER EXPNS,SIGN,EXPDS,SIGD,WHERE,PARAM,PARTLD,
     1PARTLN
      DIMENSION RNUMP(200),RNUMS(200),RDENS(200),RDENP(200),
     1ITEMP(23),IEXPN(50),IEXPD(50),PART1(50),PART2(50)
      COMMON/SEN/PARAM(3),SENSFL,FRMAX,FRMIN
      COMMON IND,NASA,MTRN1,MTRN2,MTRN3,MD,IJTAG(15,2),I
     1PRIN,Z(42),LL,MODNM(23),VALMOD(23,10),ILOOP(23),LI,LIC
     2,M9,ZZ(23),NAM(23,3),ITAG(5,8),NMBR(6),
     3M,SNUM(30,5),SDEN(30),IOD(30),IO(5),NUM(5)
     5,XG(5),IP(30,5),ID,NUMZ,DMY(23)
     4,NAME(23,2),MVI,IST(40),LIM(6),ITWO(23),LOOP(10000)
     6,WHERE,PARTLN(200,23),EXPNS
     7(200),NFN(200),PARTLD(200,23),EXPDS(200),
     8SIGD(200),NFD(200),LPN,LPD,SIGN(200)
      DATA INEG/'-   '/,IBLNK/'    '/,PART1/50*0.0/,PART2/50
     1*0.0/
      DO 2 K=1,MVI
      ITEMP(K)=NAM(K,1)
      DO 2 L=2,4
      CALL PACK(ITEMP(K),L,0,4)
    2 CONTINUE
      IF(WHERE-1)60,200,19
```

```
 19   CALL PACK(PARTLD(1,1),3,1,4)
      CALL PACK(PARTLD(1,1),4,4,4)
      NFD(1)=1
      GO TO 400
200   DO 320 I=1,LPN
      RNUMP(I)=1
      RNUMS(I)=1
      KP=NFN(I)
      DO 320 J=1,KP
      ICOMP1=0
      ICOMP2=0
      ICOMP3=0
      ICOMP4=0
      CALL PACK(ICOMP1,1,PARTLN(I,J),1)
      CALL PACK(ICOMP2,4,PARTLN(I,J),2)
      CALL PACK(ICOMP3,4,PARTLN(I,J),3)
      KL=0
205   KL=KL+1
      IF(ICOMP1.EQ.ITEMP(KL)) GO TO 210
      GO TO 225
210   IF(ICOMP2.EQ.NAM(KL,2)) GO TO 220
      GO TO 225
220   IF(ICOMP3.EQ.NAM(KL,3)) GO TO 240
225   IF(KL.LT.MVI) GO TO 205
240   CALL PACK(ICOMP4,4,PARTLN(I,J),4)
      ICOMP4=ICOMP4+1
      GO TO (250,60,60,285,280,60,290,300,60,310),ICOMP4
250   RNUMP(I)=RNUMP(I)/Z(KL)
      GO TO 285
280   RNUMP(I)=0
285   RNUMS(I)=RNUMS(I)/Z(KL)
      GO TO 316
290   RNUMP(I)=RNUMP(I)*Z(KL)
      GO TO 315
300   RNUMP(I)=RNUMP(I)*Z(KL)**2
      RNUMP(I)=-RNUMP(I)
      GO TO 315
310   RNUMP(I)=0
315   RNUMS(I)=RNUMS(I)*Z(KL)
316   IF(SIGN(I).EQ.INEG) GO TO 317
      GO TO 320
317   RNUMP(I)=-RNUMP(I)
      RNUMS(I)=-RNUMS(I)
320   CONTINUE
      GO TO 30
400   DO 2520 I=1,LPD
      KP=NFD(I)
      RDENP(I)=1
      RDENS(I)=1
      IF(I.NE.1) GO TO 402
      RDENP(I)=0
      GO TO 2520
402   DO 520 J=1,KP
      ICOMP1=0
      ICOMP2=0
      ICOMP3=0
      ICOMP4=0
      CALL PACK(ICOMP1,1,PARTLD(I,J),1)
      CALL PACK(ICOMP2,4,PARTLD(I,J),2)
      CALL PACK(ICOMP3,4,PARTLD(I,J),3)
      KL=0
405   KL=KL+1
      IF(ICOMP1.EQ.ITEMP(KL)) GO TO 410
      GO TO 425
410   IF(ICOMP2.EQ.NAM(KL,2)) GO TO 420
      GO TO 425
420   IF(ICOMP3.EQ.NAM(KL,3)) GO TO 440
425   IF(KL.LT.MVI) GO TO 405
440   CALL PACK(ICOMP4,4,PARTLD(I,J),4)
      ICOMP4=ICOMP4+1
      GO TO (450,60,60,485,480,60,490,500,60,510),ICOMP4
450   RDENP(I)=RDENP(I)/Z(KL)
```

```
      GO TO 485
480   RDENP(I)=0.0
485   RDENS(I)=RDENS(I)/Z(KL)
      GO TO 516
490   RDENP(I)=RDENP(I)*Z(KL)
      GO TO 515
500   RDENP(I)=RDENP(I)*Z(KL)**2
      RDENP(I)=-RDENP(I)
      GO TO 515
510   RDENP(I)=0.0
515   RDENS(I)=RDENS(I)*Z(KL)
516   IF(SIGD(I).EQ.INEG) GO TO 517
      GO TO 520
517   RDENP(I)=-RDENP(I)
      RDENS(I)=-RDENS(I)
520   CONTINUE
2520  CONTINUE
      J=0
      DO 610 K=1,LPD
      DO 610 I=1,LPN
      J=J+1
      IEXPN(J)=EXPNS(I)+EXPDS(K)
      IF(ABS(RDENS(K)*RNUMP(I)-RNUMS(I)*RDENP(K)).LE.1.0E-75
     1) GO TO 1520
      GO TO 1521
1520  J=J-1
      GO TO 610
1521  IF(J.EQ.1) GO TO 1620
      JMIN1=J-1
      DO 1610 KL=1,JMIN1
      IF(IEXPN(J).EQ.IEXPN(KL)) GO TO 608
      GO TO 1610
608   PART1(KL)=PART1(KL)+RDENS(K)*RNUMP(I)-RNUMS(I)*RDENP(K
     1)
      J=J-1
      GO TO 610
1610  CONTINUE
1620  PART1(J)=RDENS(K)*RNUMP(I)-RNUMS(I)*RDENP(K)
610   CONTINUE
      IF(J.LE.1) GO TO 640
      JJ=1
631   K=JJ+1
      IF(ABS(PART1(JJ)).LE.1.0E-75) GO TO 636
632   IF(IEXPN(JJ).GT.IEXPN(K)) GO TO 634
      TEMP1=PART1(JJ)
      TEMP2=IEXPN(JJ)
      PART1(JJ)=PART1(K)
      IEXPN(JJ)=IEXPN(K)
      PART1(K)=TEMP1
      IEXPN(K)=TEMP2
634   K=K+1
      IF(K.GT.J) GO TO 636
      GO TO 632
636   IF(JJ.EQ.(J-1)) GO TO 640
      JJ=JJ+1
638   GO TO 631
640   WRITE(6,900) (ITAG(1,K),K=1,8),(PARAM(K),K=1,3)
      IF(J)60,641,642
641   WRITE(6,906)
      GO TO 643
642   SET=0
      DO 710 K=1,J
      IF(ABS(PART1(K)).LT.1.0E-75) GO TO 710
      SET=1
 700  WRITE(6,901) PART1(K),IEXPN(K)
710   CONTINUE
      IF(SET.EQ.0) WRITE(6,906)
643   J1=J
      J=0
      DO 611 K=1,LPD
      DO 611 I=1,LPD
      J=J+1
```

```
      IEXPD(J)=EXPDS(I)+EXPDS(K)
      IF(ABS(RDENS(K)*RDENS(I)).LE.1.0E-75) GO TO 1711
      GO TO 1712
1711  J=J-1
      GO TO 611
1712  IF(J.EQ.1) GO TO 1612
      JMIN1=J-1
      DO 1611 KL=1,JMIN1
      IF(IEXPD(J).EQ.IEXPD(KL)) GO TO 609
      GO TO 1611
609   PART2(KL)=PART2(KL)+RDENS(K)*RDENS(I)
      J=J-1
      GO TO 611
1611  CONTINUE
1612  PART2(J)=RDENS(K)*RDENS(I)
611   CONTINUE
      IF(J-1)60,749,740
740   JJ=1
741   K=JJ+1
      IF(ABS(PART2(JJ)).LE.1.0E-75) GO TO 746
742   IF(IEXPD(JJ).GT.IEXPD(K)) GO TO 744
      TEMP1=PART2(JJ)
      TEMP2=IEXPD(JJ)
      PART2(JJ)=PART2(K)
      IEXPD(JJ)=IEXPD(K)
      PART2(K)=TEMP1
      IEXPD(K)=TEMP2
744   K=K+1
      IF(K.GT.J) GO TO 746
      GO TO 742
746   IF(JJ.EQ.(J-1)) GO TO 749
      JJ=JJ+1
748   GO TO 741
749   WRITE(6,902)
      DO 750 K=1,J
      IF(ABS(PART2(K)).LT.1.0E-75) GO TO 750
      WRITE(6,901) PART2(K),IEXPD(K)
750   CONTINUE
      IF(FRMAX.EQ.0.0.AND.FRMIN.EQ.0.0) GO TO 30
      FRINC=(FRMAX-FRMIN)/199.0
      FREQ=FRMIN
      WRITE(6,904)
      DO 763 KK=1,200
      FREQ1=2.0*3.1415926535*FREQ
      CFREQ=CMPLX(0.0,FREQ1)
      CTEMP=(0.0,0.0)
      DO 755 K=1,J1
      CTEMP1=CMPLX(PART1(K),0.0)
      IF(IEXPN(K).LT.0) GO TO 754
      CTEMP=CTEMP+CTEMP1*CFREQ**IEXPN(K)
      GO TO 755
 754  CTEMP=CTEMP+CTEMP1/CFREQ**(IABS(IEXPN(K)))
755   CONTINUE
      CTEMPB=(0.0,0.0)
      DO 760 K=1,J
      CTEMP1=CMPLX(PART2(K),0.0)
      IF(IEXPD(K).LT.0) GO TO 759
      CTEMPB=CTEMPB+CTEMP1*CFREQ**IEXPD(K)
      GO TO 760
 759  CTEMPB=CTEMPB+CTEMP1/CFREQ**(IABS(IEXPD(K)))
760   CONTINUE
      IF(CABS(CTEMPB).LT.1.0E-74) GO TO 1762
      CTEMP=CTEMP/CTEMPB
      RMAGN=CABS(CTEMP)
      ANGLE=ATAN2(AIMAG(CTEMP),REAL(CTEMP))
762   WRITE(6,905) FREQ,RMAGN,ANGLE
1762  FREQ=FREQ+FRINC
763   CONTINUE
      GO TO 30
900   FORMAT(' ',/1X,31HNUMERATOR POLYNOMIAL : SENSITIV
     1,'ITY OF ',2A1,2I1,
     21H/,2A1,2I1,2X,4HTO  ,A1,2I1)
```

```
901   FORMAT(' ',/,1X,E11.4,10H TIMES S**,I3)
902   FORMAT(' ',////,1X,27HDENOMINATOR POLYNOMIAL :  S
     1,'ENSITIVITY')
903   FORMAT(' ',//,' ','MACHINE FAILURE')
904   FORMAT(' ',////' ','EVALUATION OF SENSITIVITY',
     1///,' ','FREQUENCY'
     2,10X,'MAGNITUDE',10X,'PHASE(IN RADIANS)',/,' ')
905   FORMAT(' ',E11.4,8X,E11.4,8X,E11.4)
906   FORMAT(' ',//,' ','IDENTICALLY ZERO',//,' ')
 60   WRITE(6,903)
30    RETURN
      END
```

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13. ABSTRACT

A study and pursuant development is described of a digital computer program for the computation of transfer function sensitivities in a symbolic form suitable for storage and subsequent repetitive numerical evaluation over a range of frequencies or parameter values. The algorithm is implemented in conjunction with the Network Analysis for Systems Applications Program (NASAP) developed by R. S. Schwartz at Northeastern University. Several example problems, as well as suggestions for possible improvement of the algorithm and its extrapolation into the areas of optimization and automatic design, are included.

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